MAC Sublayer(28)

Summary of channel allocation methods:

Method	Description
FDM	Dedicate a frequency band to each station
TDM	Dedicate a time slot to each station
Pure ALOHA	Unsynchronized transmission at any instant
Slotted ALOHA	Random transmission in well-defined time slots
1-persistent CSMA	Standard carrier sense multiple access
Nonpersistent CSMA	Random delay when channel is sensed busy
P-persistent CSMA	CSMA, but with a probability of p of persisting
CSMA/CD	CSMA, but abort on detecting a collision
Bit map	Round robin scheduling using a bit map
Binary countdown	Highest numbered ready station goes next
Tree walk	Reduced contention by selective enabling
Wavelength division	A dynamic FDM scheme for fiber
MACA, MACAW	Wireless LAN protocols
GSM	FDM plus TDM for cellular radio
CDPD	Packet radio within an AMPS channel
CDMA	Everybody speak at once but in a different language
Ethernet	CSMA/CD with binary exponential backoff
Token bus	Logical ring on a physical bus
Token ring	Capture the token to send a frame
DQDB	Distributed queuing on a two-bus MAN
FDDI	Fiber-optic token ring
HIPPI	Crossbar using 50-100 twisted pairs
Fibre channel	Crossbar using fiber optics
SPADE	FDM with dynamic channel allocation
ACTS	TDM with centralized slot allocation
Binder	TDM with ALOHA when slot owner is not interested
Crowther	ALOHA with slot owner getting to keep it
Roberts	Channel time reserved in advance by ALOHA

Network Layer(1)

Principal service:

Getting packets from the source all the way to the destination

---> is the lowest layer that deals with end-to-end transmission

To achieve this goal, the network layer

- must know about the topology of the communication subnet, i.e. the set of all routers
- choose appropriate paths through it (routing)
- control or even prevent overload on one side and idleness on the other (congestion control)
- deal with the differences of diverse networks involved (internetworking)

Requested properties of the network layer services:

1. The services should be independent of the subnet technology.
2. The transport layer should be shielded from the number, type, and topology of the subnets present.
3. The network addresses made available to the transport layer should use a uniform numbering plan, even across LANs and WANs.

Network Layer(2)

Two principal alternatives:

- network is connection-oriented (setup required) and reliable, like the telephone system
- network is connectionless (no setup required) and unreliable, like the postal system

Two basic philosophies for organizing the subnet:

- virtual circuits (identity of the connection)
- datagram (identity of the independent packet)

Comparison of datagram and virtual circuit subnets

Issue	Datagram subnet	VC subnet
Circuit setup	Not needed	Required
Addressing	Each packet contains the full source and destination address	Each packet contains a short VC number
State information	Subnet does not hold state information	Each VC requires subnet table space
Routing	Each packet is routed independently	Route chosen when VC is set up; all packets follow this route
Effect of router failures	None, except for packets lost during the crash	All VCs that passed through the failed router are terminated
Congestion control	Difficult	Easy if enough buffers can be allocated in advance for each VC

Network Layer(3)

Routing algorithms

Responsible for deciding which output line an incoming packet should be transmitted on.

Two major classes of routing algorithms:

- nonadaptive
- adaptive

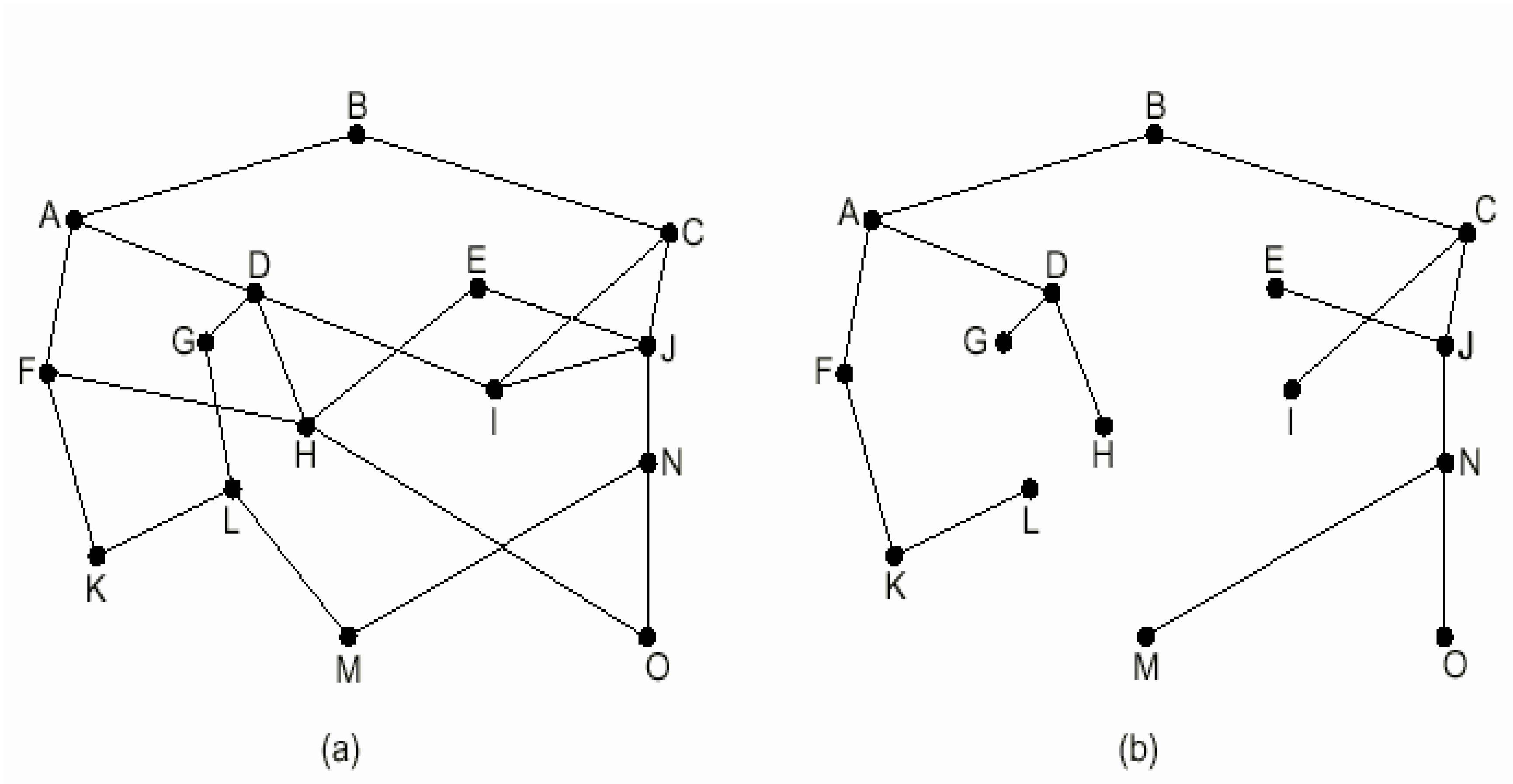
The Optimality Principle:

If router J is on the optimal path from router I to router K, then the optimal path from J to K also follows the same route

---> The set of optimal routes from all sources to a given destination form a tree rooted at the destination.

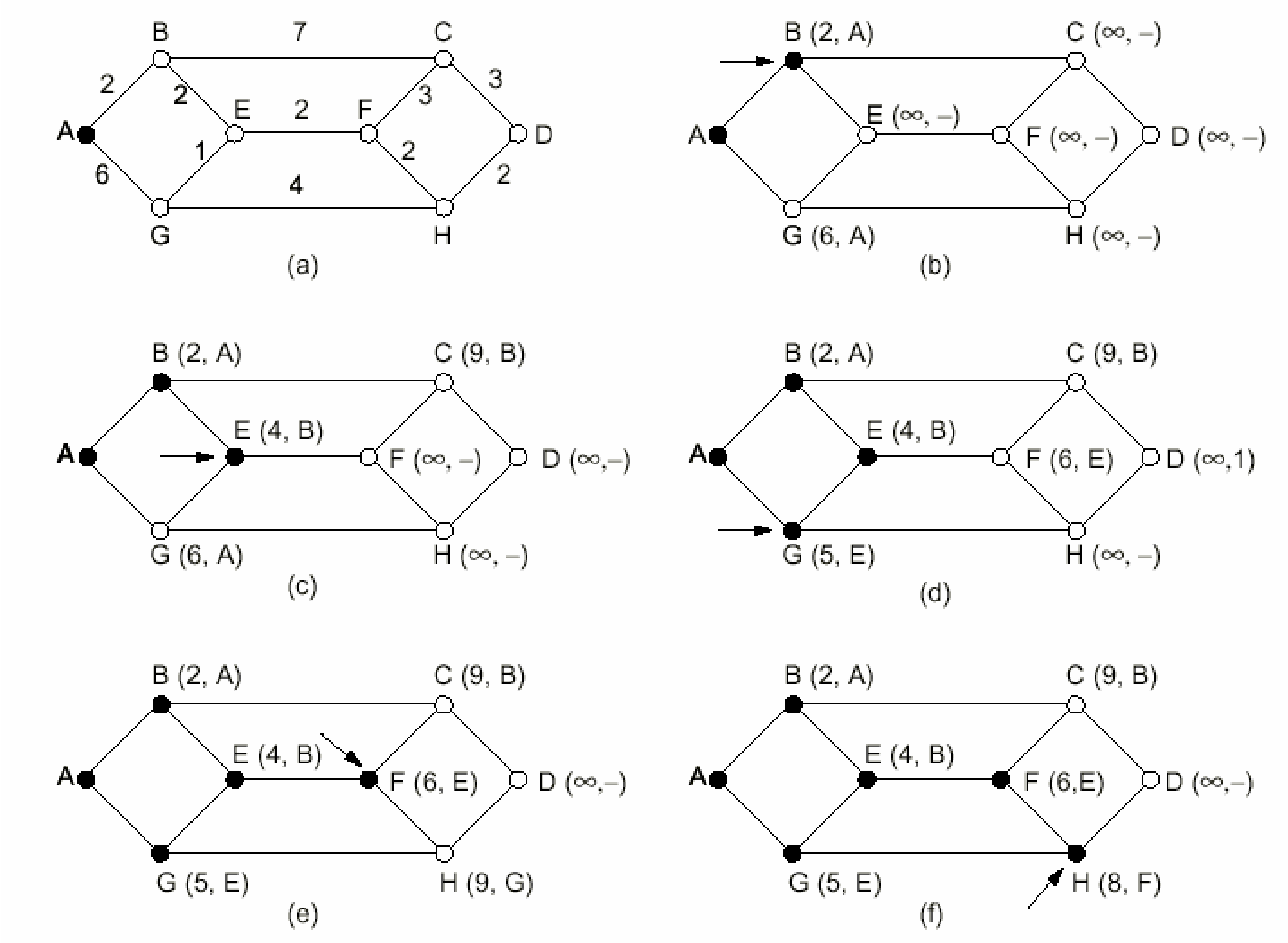
Network Layer(4)

Example of a sink tree



Network Layer(5)

Example for finding the shortest path



Network Layer(6)

Possible measures for determining path length:

- number of hops
- geographic distance
- bandwidth
- average traffic (load)
- communication cost
- mean queue length
- measured delay

Flooding

Idea:

Every incoming packet is sent out on every outgoing line except the one it arrived on

Measure to damp unlimited duplication of packets:

- Decrementing a hop counter
- Selective flooding (only those which go in the right direction)

Possible applications:

- military
- using as a metric against which other routing algorithms can be compared

Network Layer(7)

Flow-Based Routing

Idea:

In addition to topology also load is considered

Possible applications:

In networks where the mean data flow between each pair of nodes is relatively stable and predictable

Distance Vector Routing

Idea:

Each router maintains a table (vector) giving a periodically updated best known distance to each destination and which line to use to get there

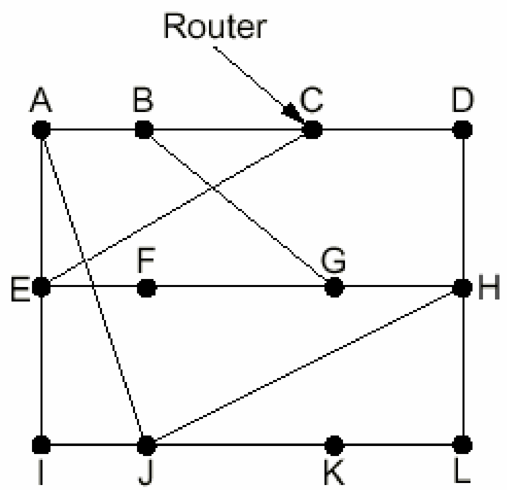
---> It is a *dynamic* routing algorithm

Used in early versions of

- ARPANET
- Internet
- DECnet
- Novell´s IPX
- AppleTalk
- Cisco routers

Network Layer(8)

Example of the updating process



(a)

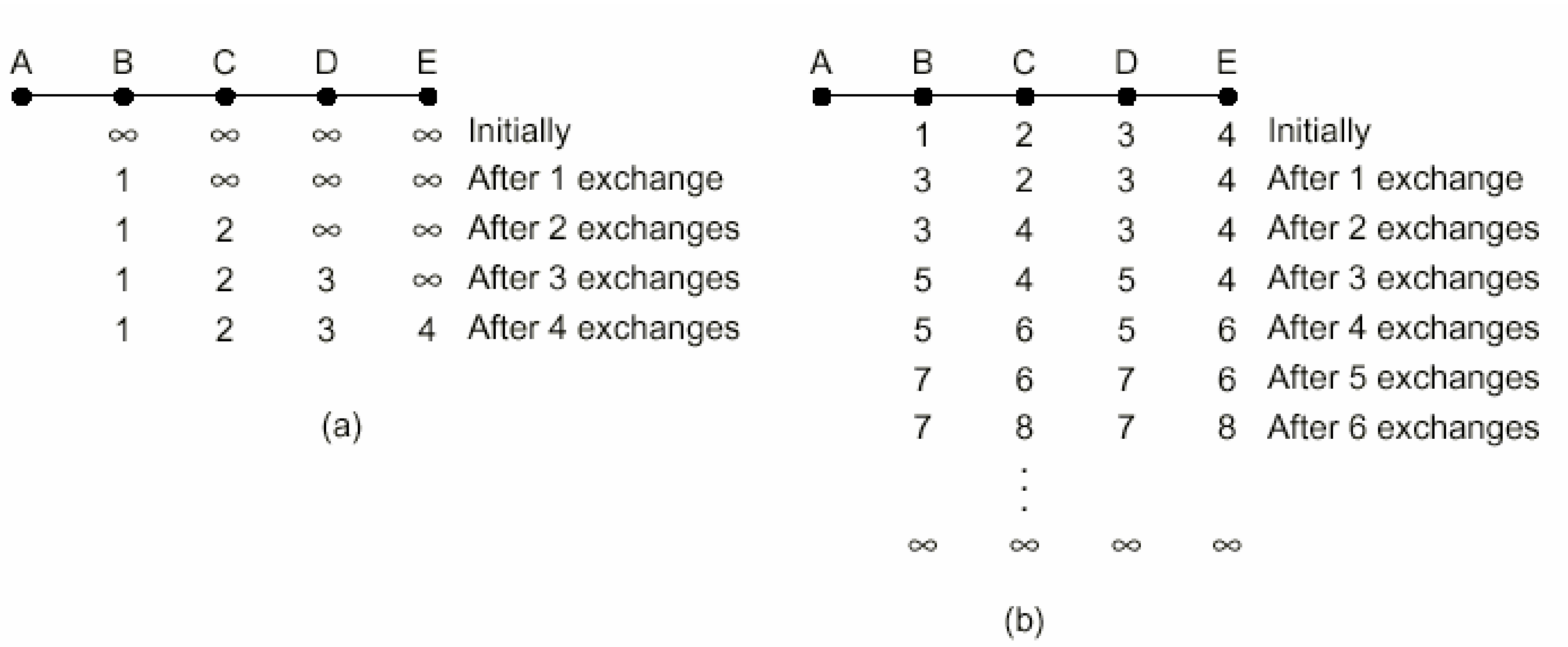
To	A	I	H	K	New estimated delay from J	Line
A	0	24	20	21	8	A
B	12	36	31	28	20	A
C	25	18	19	36	28	I
D	40	27	8	24	20	H
E	14	7	30	22	17	I
F	23	20	19	40	30	I
G	18	31	6	31	18	H
H	17	20	0	19	12	H
I	21	0	14	22	10	I
J	9	11	7	10	0	–
K	24	22	22	0	6	K
L	29	33	9	9	15	K
	JA delay is 8	JI delay is 10	JH delay is 12	JK delay is 6	New routing table for J	

Vectors received from J's four neighbors

(b)

Network Layer(9)

Example of the count-to-infinity problem

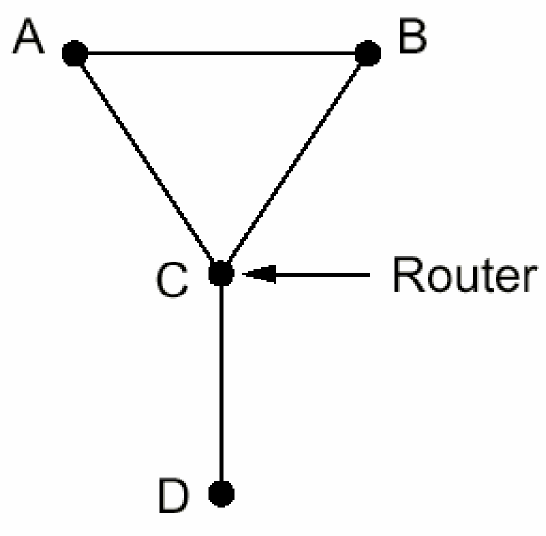


Main problems:
- The algorithm often takes too long to converge to infinity
- How to define infinity?

The Split Horizon Hack
Idea:
The distance to X is reported as infinity on the line that packets for X are sent on

Network Layer(10)

Example where split horizon fails



Link State Routing

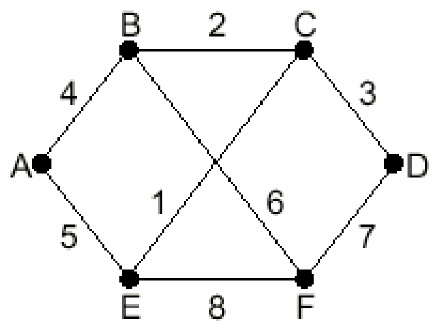
Idea:

Each router must

- discover its neighbors and learn their network addresses.
- measure the delay or cost to each of its neighbors.
- construct a packet telling all it has just learned.
- send this packet to all other routers using flooding.
- compute the shortest path to every other router using shortest path algorithm.

Network Layer(11)

Example of building Link State Packets



(a)

Link State Packets

A	B	C	D	E	F
Seq.	Seq.	Seq.	Seq.	Seq.	Seq.
Age	Age	Age	Age	Age	Age
B 4	A 4	B 2	C 3	A 5	B 6
E 5	C 2	D 3	F 7	C 1	D 7
	F 6	E 1		F 8	E 8

(b)

The principle of Link State Routing is widely used in actual networks (e.g. IP).

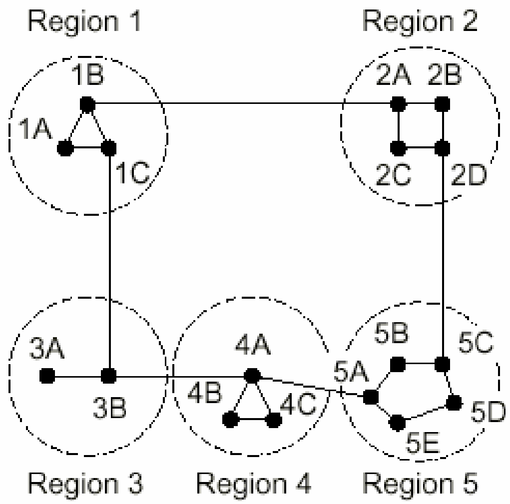
Hierarchical Routing

Idea:

Routers are divided into (sub)regions, thus making up a multilevel hierarchy.

Network Layer(12)

Example of routing in a two-level hierarchy with five regions



(a)

Full table for 1A

Dest.	Line	Hops
1A	–	–
1B	1B	1
1C	1C	1
2A	1B	2
2B	1B	3
2C	1B	3
2D	1B	4
3A	1C	3
3B	1C	2
4A	1C	3
4B	1C	4
4C	1C	4
5A	1C	4
5B	1C	5
5C	1B	5
5D	1C	6
5E	1C	5

(b)

Hierarchical table for 1A

Dest.	Line	Hops
1A	–	–
1B	1B	1
1C	1C	1
2	1B	2
3	1C	2
4	1C	3
5	1C	4

(c)

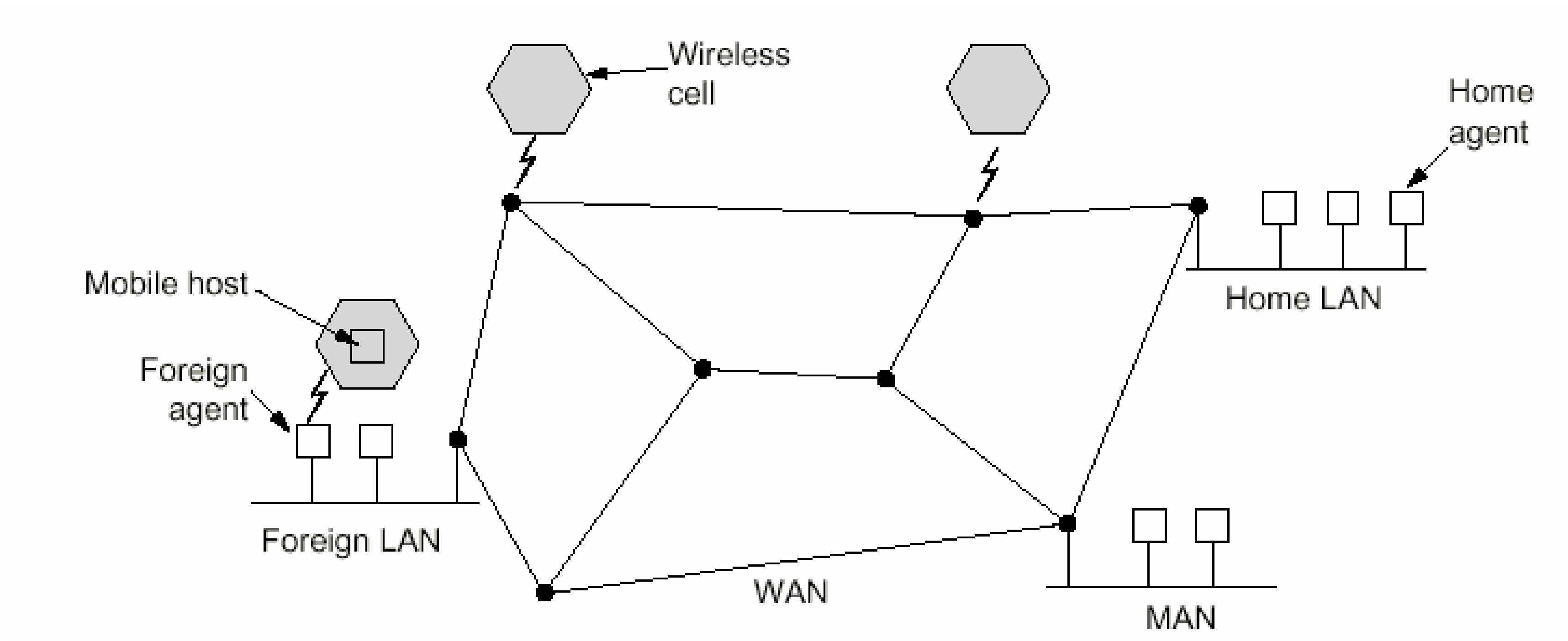
Network Layer(13)

Routing for mobile hosts

New problem:

Finding the network (LAN, MAN, wireless cell) where to route a packet to a mobile host

Model of the World (WAN)



Network Layer(14)

Registration procedure for a mobile user entering a new area:

1. Periodically, each foreign agent broadcasts a packet announcing its existence and address. A newly arrived mobile host may wait for one of these messages, but if none arrives quickly enough, the mobile host can broadcast a packet saying: „Are there any foreign agents around?“

2. The mobile host registers with the foreign agent, giving its home address, current data link layer address, and some security information.

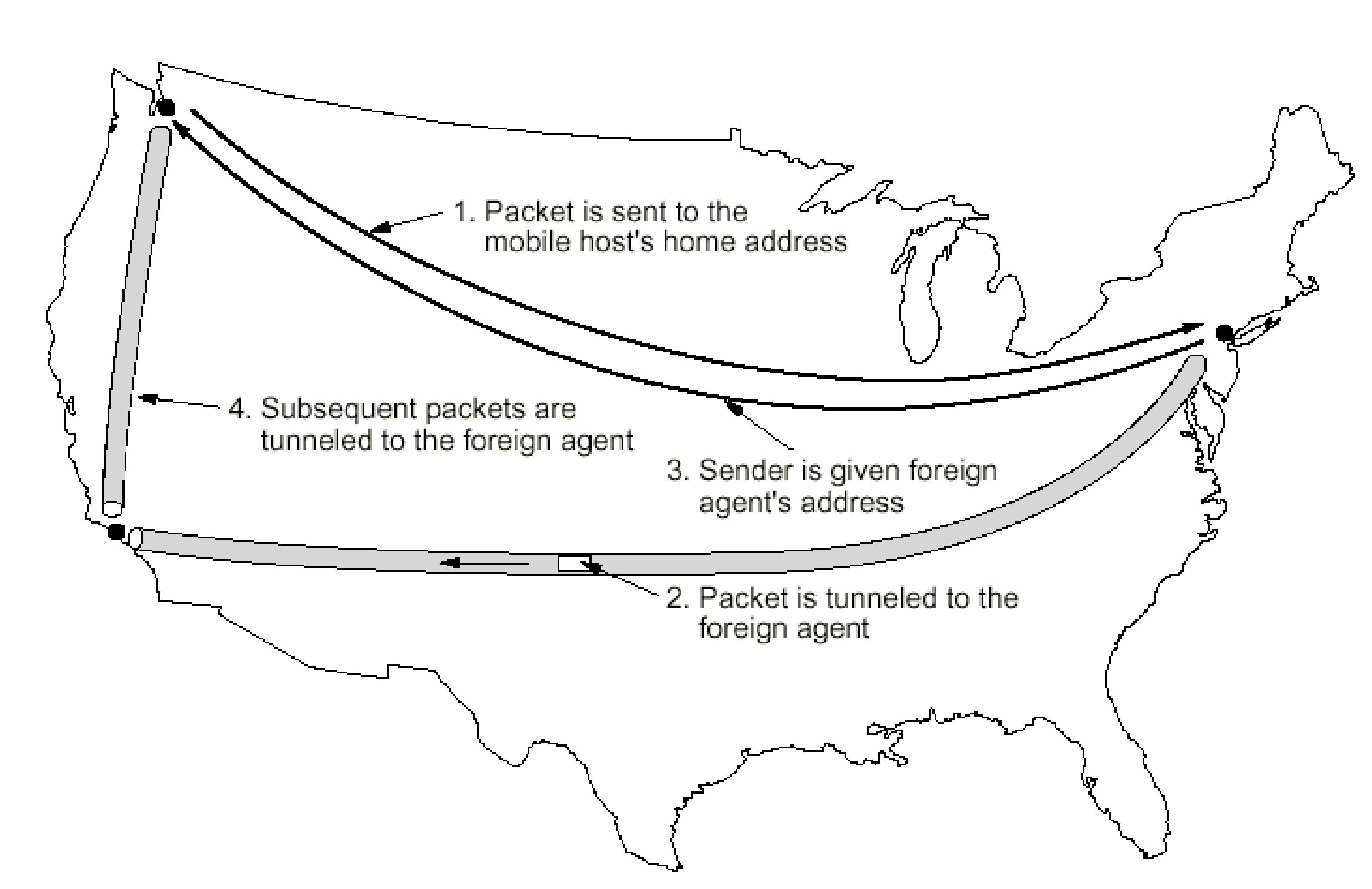
3. The foreign agent contacts the mobile host`s home agent and says: „One of your hosts is over here.“ The message from the foreign agent to the home agent contains the foreign agent´s network address. It also includes the security information, to convince the home agent that the mobile host is really there.

4. The home agent examines the security information, which contains a timestamp, to prove that it was generated within the past few seconds. If it is happy, it tells the foreign agent to proceed.

5. When the foreign agent gets the acknowledgement from the home agent, it makes an entry in its tables and informs the mobile host that it is now registered.

Network Layer(15)

Packet routing for mobile users



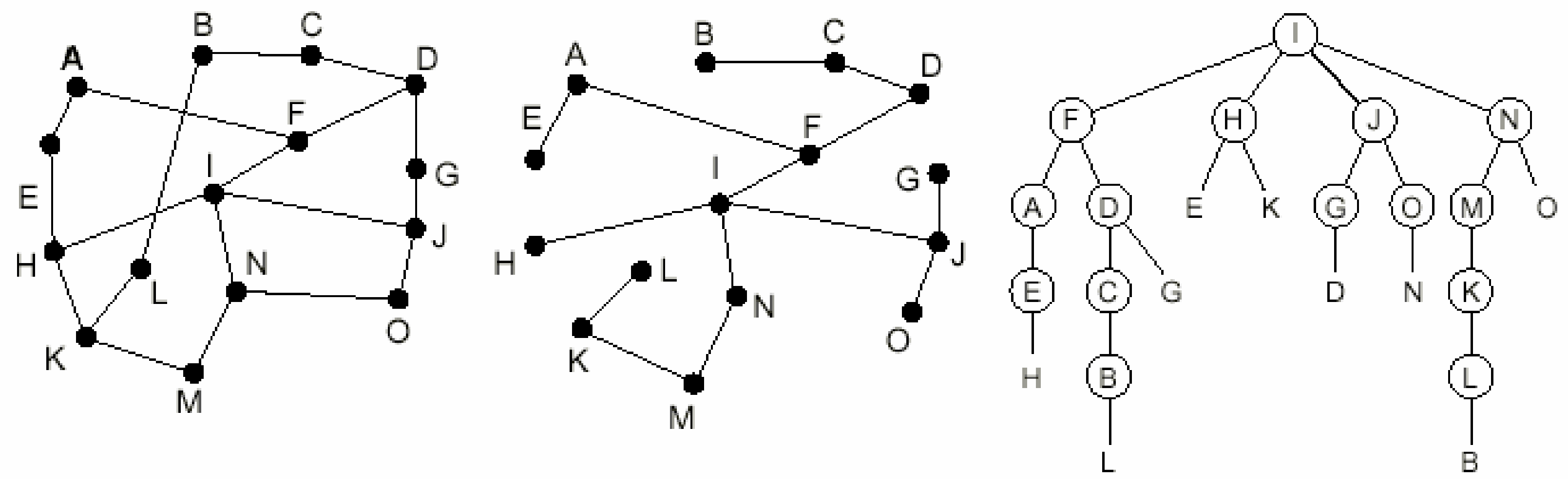
Network Layer(16)

Broadcast Routing

Possible methods:

- the source sends a distinct packet to each destination
- flooding
- **reverse path ordering**

Example of reverse path ordering



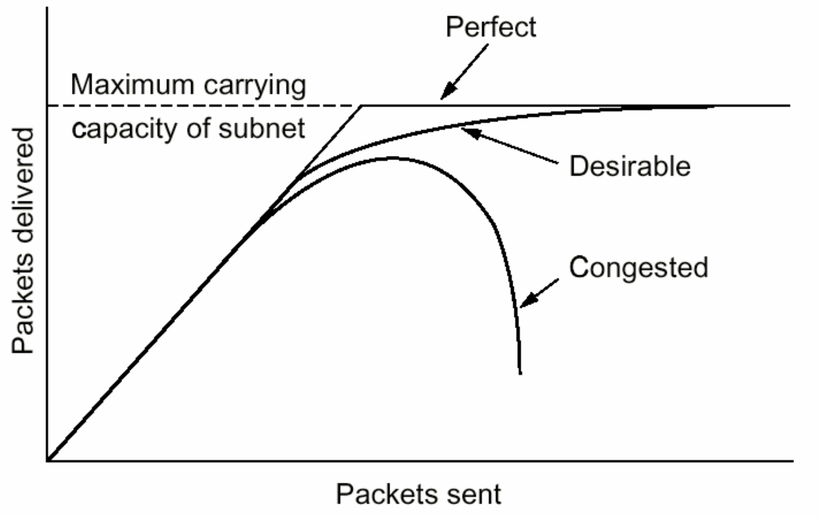
(a) (b) (c)

Network Layer(17)

Congestion Control

Responsible for dealing with the problem of performance degradation due to too much traffic

Depicting the symptom



Factors contributing to congestion:

- burst of packets on several input lines requesting the same output line
- insufficient memory to hold packets
- slow router processors

Congestion control is a global issue, flow control relates to the point-to-point traffic!

Network Layer(18)

Two basic solution approaches to congestion control

- open loop
- closed loop

Open loop

Fault prevention approach, i.e. systems are designed to prevent (minimize) congestion by good design

Appropriate policies for good design at various layers

Layer	Policies
Transport	• Retransmission policy • Out-of-order caching policy • Acknowledgement policy • Flow control policy • Timeout determination
Network	• Virtual circuits versus datagram inside the subnet • Packet queueing and service policy • Packet discard policy • Routing algorithm • Packet lifetime management
Data link	• Retransmission policy • Out-of-order caching policy • Acknowledgement policy • Flow control policy

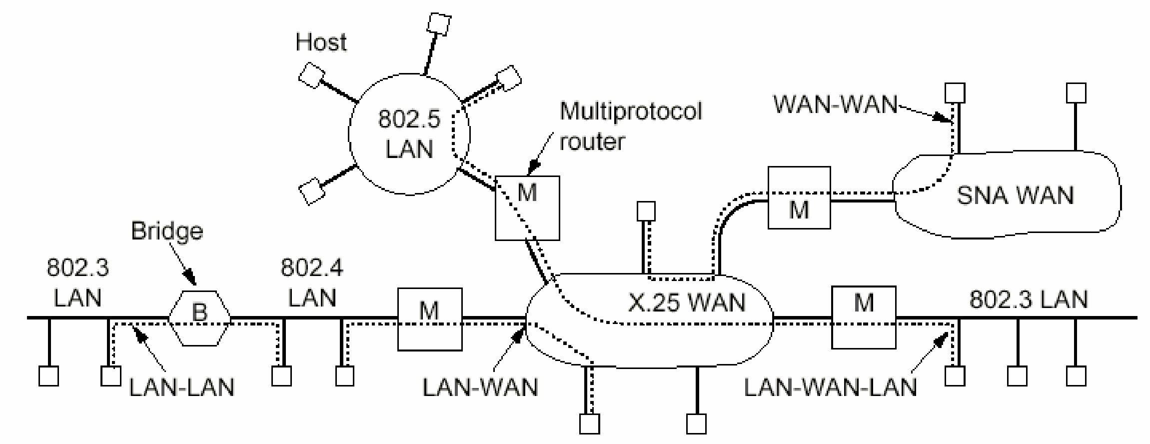
Network Layer(19)

Internetworking

Idea:

Packets travel through different networks with different technology using different protocols in every layer

Depicting network interconnection



Functionality of the black box connecting two networks depends on the involved layer:

Layer 1: Repeaters copy individual bits between cable segments.
Layer 2: Bridges store and forward data link frames between LANs.
Layer 3: Multiprotocol routers forward packets between dissimilar networks.
Layer 4: Transport gateways connect byte streams in the transport layer.
Above 4: Application gateways allow interworking above layer 4.

Network Layer(20)

Differences than can occur in the network layer

Item	Some Possibilities
Service offered	Connection-oriented versus connectionless
Protocols	IP, IPX, CLNP, AppleTalk, DECnet, etc.
Addressing	Flat (802) versus hierarchical (IP)
Multicasting	Present or absent (also broadcasting)
Packet size	Every network has its own maximum
Quality of service	May be present or absent; many different kinds
Error handling	Reliable, ordered, and unordered delivery
Flow control	Sliding window, rate control, other, or none
Congestion control	Leaky bucket, choke packets, etc.
Security	Privacy rules, encryption, etc.
Parameters	Different timeouts, flow specifications, etc.
Accounting	By connect time, by packet, by byte, or not at all

Network Layer(21)

Summary:

- it provides service to the transport layer
- it can be based on either virtual circuits or datagrams
- its main job is routing packets from the source to the destination
  - static routing algorithms include
    - shortest path routing
    - flooding
    - flow-based routing
  - dynamic routing algorithms (used by most actual networks) include
    - distance vector routing
    - link state routing
  - other important routing topics are
    - hierarchical routing
    - routing for mobile hosts
    - broadcast routing